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# A Holocene sea-level curve constructed from a single core at Osaka, Japan (A preliminary note)

Fujio Masuda*, Toshiaki Irizuki**, Osamu Fujiwara***, Basara Miyahara**** and Syusaku Yoshikawa*****

* *Department of Geology and Mineralogy, Graduate School of Science, Kyoto University, Kyoto 606–8502, Japan*
** *Department of Earth Sciences, Aichi University of Education, Kariya 448–8542*
*** *Tono Geoscience Center, Japan Nuclear Cycle Development Institute, Toki 509–5102*
**** *Geographical Survey Institute, Tsukuba 305–0821*
***** *Department of Geosciences, Faculty of Science, Osaka City University, Osaka 558–8585*

## ABSTRACT

A relative sea-level curve has been drawn based on 25 AMS $^{14}C$ ages and paleodepths inferred from ostracodes in a Holocene core from Kitatsumori, Osaka, Japan. This is the first relative sea-level curve constructed from a single continuous core in siliciclastic sediments. The new curve indicates that the first flooding at this site was −21.5 m in depth below present mean sea-level at about 9200 calendar years B.P., that the maximum sea-level highstand of about +1.5 m was at 5500 to 5000 calendar years B.P. (about 800 years younger than previously thought), and that a relative sea-level decrease of about −1.2 m took place at about 2200 calendar years B.P. and that a relative sea-level increase of about +0.7 m occurred about 1700 calendar years B.P.

## INTRODUCTION

A Holocene relative sea-level curve for a district has been constructed from the relationship between the $^{14}C$ ages of intertidal mollusc shells and their elevations and/or depths of occurrence. Many relative sea-level curves for modern coastal areas in Japan have been published by Ota et al. (1982, 1990) and indicate that a maximum highstand occurred at 6000 to 5000 $^{14}C$ yr B.P. and was 2 to 5 meters higher than at present. The marine transgressive stage is said to have begun at about 10000 $^{14}C$ yr B.P. at several tens of meters in depth below present sea-level, and the ensuing regressive stage is said to have occurred at 6000 to 5000 $^{14}C$ yr B.P. In reality, Japan in the Holocene experienced a higher-rate and longer-term transgression followed a lower-rate and shorter-term regression. The relative sea-level curves in Japan give some important information for cause of sea-level change, because the phenomena differ from those of Europe and East Coast of USA, showing a maximum highstand in present, and are similar to those of an estimated eustatic curves (cf. Morner, 1976; Tooley, 1985; Bird, 1993; Cronin, 1999).

Relative sea-level changes, even within a single basin, show a significant spatial dependence owing to differences in tectonics, isostatic response (Nakata et al., 1991) and sediment flux (Jervey, 1988). As is well-known, relative sea-level changes in areas uplifted by great earthquakes in the trench along the southern parts of the Boso and Miura peninsulas in Japan differ from those in surrounding areas (Masuda, 1998; Fujiwara et al., 1999b; Masuda et al., 2001). Accordingly, a relative sea-level curve must be constructed for each locality. In this paper we construct a relative sea-level curve based on the information from a single core.

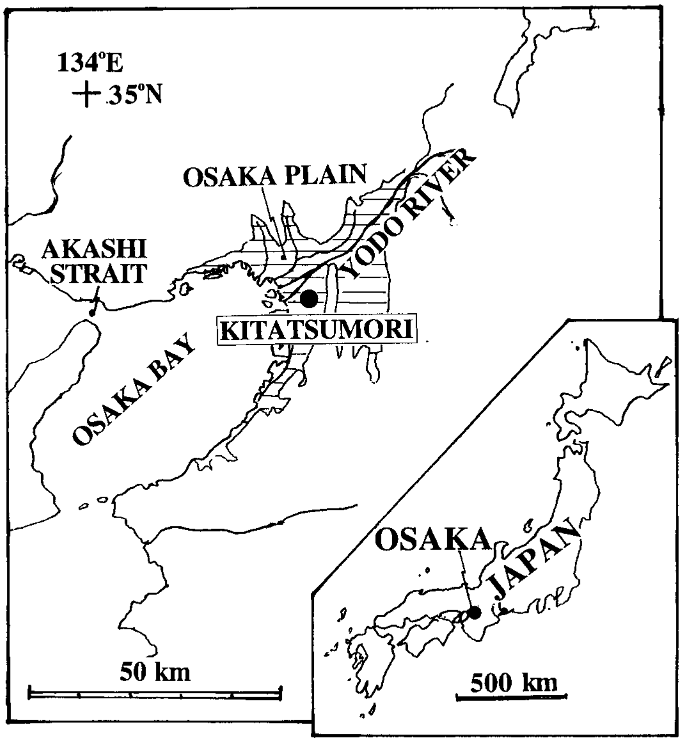


**Fig. 1.** Location of the study core collected from a delta plain at Kitatsumori, Osaka, Kinki district, Japan.

## LOCALITY AND FACIES OF THE HOLOCENE CORE

A core used to construct a sea-level curve for this study was collected at Kitatsumori, Osaka City (N34°48'49", E135°59'9"), on the delta plain of the Yodo River (−0.27 m in elevation) (Fig. 1) and was drilled by Osaka City. Stratigraphy of the core, 250 m long was reported by Yoshikawa et al. (1998). The Holocene sequence in the upper part of the core is about 21 m long, of which the uppermost 5 m were not recovered. The Holocene sediments conformably overlie uppermost Pleistocene fluvial deposits consisting of cross-bedded sand and gravel (channel deposits), and muds with rootlets (flood deposits) (Fig. 2). The boundary between the uppermost Pleistocene and the Holocene is the so-called "transgressive surface," which refers to the first marine flooding surface (Van Wagoner et al., 1988).

The Holocene sequence above the transgressive surface is composed of marine sediments and is divided into lower, middle and upper parts (Fig. 2). The lower part, about 4 m thick at a depth of −22 to −18 m (elevation), is composed of clay with thin sand and silt layers. The lower clay contains burrows as well as intercalations of thin peat layers. The sand and silt layers exhibit cross-laminations and grain imbrications that imply opposing bi-directional paleocurrents. The middle to upper clays include abundant marine fossils, such as molluscs, ostracodes, diatoms and foraminifers, and show strong bioturbation. Framboidal pyrites, which indicate an anoxic environment, are present in the clays. These deposits suggest an environment consisting of a tidally-influenced estuary to narrow bay floor that was formed during the early stage of a transgressive period.

The middle part of the Holocene sequence, about 7 m thick at a depth of −18 to −11 m, is sandy silt that also contains marine fossils. The silt intercalates with thin beds of well-sorted and very fine sand that is easily transported by weak wave-

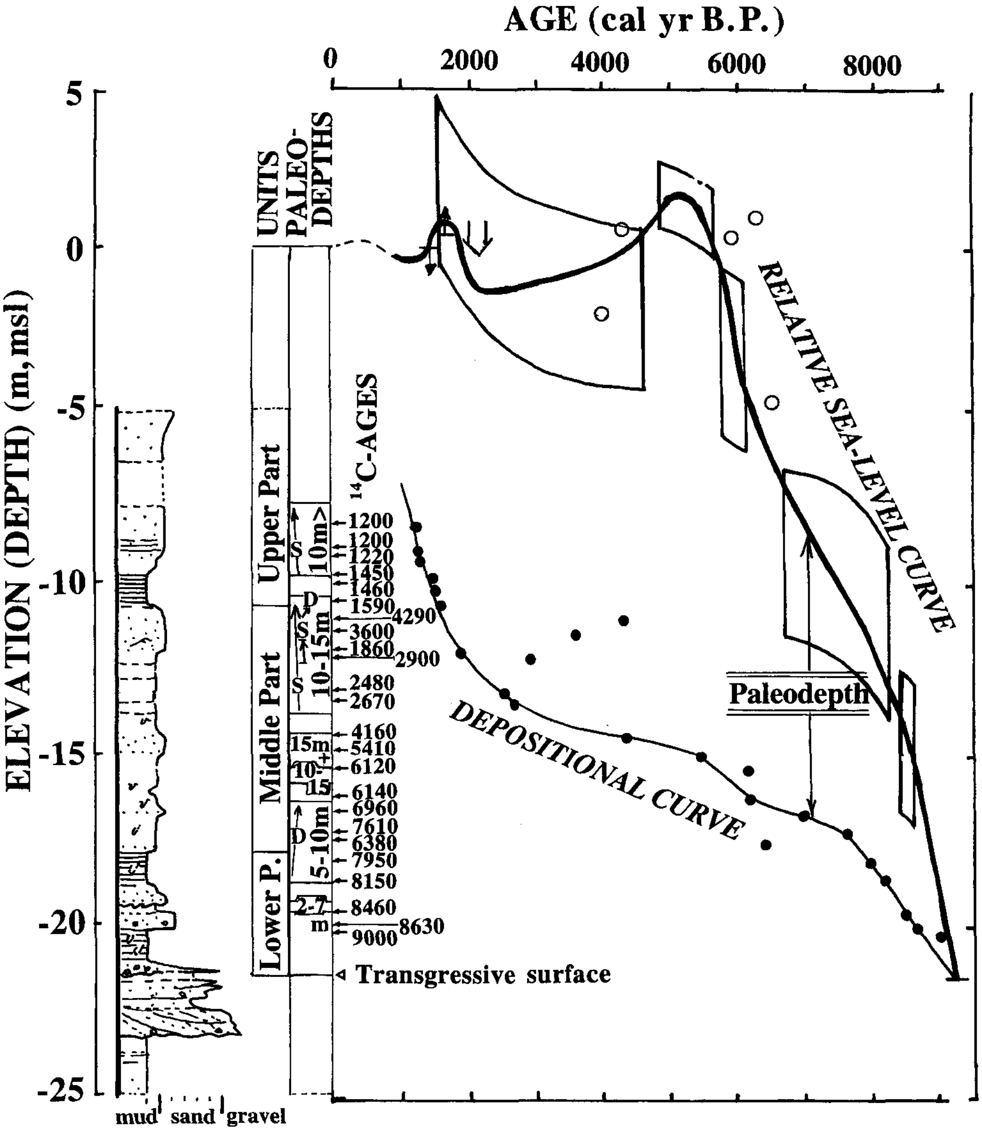


**Fig. 2.** Depositional environments, "depositional curve" and relative sea-level curve reconstructed for a single Holocene core in Osaka, Japan. Depositional environments were inferred from facies analysis. These curves were drawn from $^{14}$C ages, sampling elevations, and paleodepths. Solid line = relative sea-level change; squares = paleodepths estimated from numerical analysis of ostracode fauna; solid circles = $^{14}$C ages determined in this core; open circles = $^{14}$C ages of intertidal fossil shells from other cores in Osaka reported by Maeda (1978) and Ota et al. (1988). S and D in colum of paleodepth show shallowing- and deepening-upward trends, respectively.

and/or tidal-current for long distances. Wave ripple and combined-flow ripple-laminations (Masuda and Yokokawa, 1993) are present in the sand beds. The sand and silt grains are covered by a thin film of clay, which is an indicator of deposition from flood waters. The sand may have been transported from Akashi Strait by increased tidal currents during a rise in sea-level, since such relatively coarse material originates from Akashi Strait by tidal currents in the modern Osaka Bay. This middle part of the Holocene sequence represents an open bay floor at a sea-level highstand.

The upper part of the Holocene sequence, about 11 m thick at a depth of −11 to 0 m, is clay and sand to sandy gravel in a coarsening-upward succession that was formed by a prograding delta system. Clean clay in the lower portion of this sequence represents bottomset deposits. Sand in the middle portion of this sequence represets foreset (delta front) deposits. Cross-laminations in the sand have mud drapes, reactivation surfaces, and opposing bi-directional paleocurrents that are representative of typical tidal deposits (Nio and Yang, 1989). Coarser deposits of gravely sand, which may be fluvial deposits, are reported from the uppermost part of this sequence (absent in this core) at a nearby locality (Furutani, 1989). These uppermost sediments are topset (delta plain) deposits. The delta was likely formed by the modern Yodo River, based on the location of this borehole.

## PALEODEPTHS ESTIMATED FROM FOSSIL OSTRACODES

Paleodepths, the water depths at which deposition took place, are estimated from fossil ostracode assemblages in this core. Twenty-seven samples were collected from this Holocene core. Eighty grams of dried sediment were washed through a 200 mesh sieve (75 μm) and dried again. About 200 individuals were picked from the fraction coarser than 125 μm (115 mesh). The number of ostracode specimens refers to the minimum number of individuals, which was determined by the larger of the two numbers representing either the left or right valves of each species. Methods of fossil ostracode analysis have been described in detail elsewhere (Irizuki et al., 1998).

A total of forty species was found in the core samples, and vertical changes in some fossil ostracodes in the core are shown in Fig. 3. Six units based on fossil ostracode assemblages are distinguished from the lower to the upper part of the succession: Assemblage (1) at −19.7 to −19.5 m in depth represents an inner bay at 2 to 7 m water depth. The assemblage is characterized by the dominance of *Spinileberis quadriaculeata* with minor amounts of Abe and Choe's (1988) form M of *Bicornucythere bisanensis*, *Pistocythereis bradyi* and *Trachyleberis scabrocuneata*. *Spinileberis quadriaculeata* predominates on muddy bottoms at water depths of 2 to 7 m around Japan (Ikeya and Shiozaki, 1993). Assemblage (2) at −19.0 to −16.5 m in depth represents an inner to middle bay at 5 to 10 m water depth. The assemblage is characterized by the occurrence of Abe and Choe's (1988) form A of *B. bisanensis*, *S. quadriaculeata* and *Callistocythere alata*. *Bicornucythere bisanensis* and *C. alata* live abundantly in closed middle bays on muddy bottoms at 5 to 10 m water depth (e.g., Ishizaki, 1969; Ikeya and Shiozaki, 1993). Assemblage (3) to (5) at −16.0 to −10.5 m in depth is characterized by the occurrence of *Ambtonia obai*, which commonly lives on muddy bottoms in the middle parts of bays at more than 10 m water depth (e.g., Ishizaki, 1971; Frydl, 1982; Bodergat and Ikeya, 1988; Iwasaki, 1992; Yamane, 1998). Assemblage (3) at −16.0 to −15.4 m in depth was examined in greater detail and is characterized by *Amphileberis nipponica*, *Kobayashiina hyalinosa* and *Krithe japonica*, which are common in the middle parts of bays at water depths of more than 15 m (e.g., Frydl, 1982; Yamane, 1998), but these taxa are few or absent. The paleodepth in this unit, therefore, is interpreted to be 10 to 15 m. Assemblage (4) at −15.4 to −14.5 m in depth represents the deepest facies in this succession. This assemblage implies a slightly open middle bay environment, because the number of species overall and the relative abundance of *A. obai* are at a maximum in this interval. Assemblage (5) at −14.0 to −10.5 m in depth indicates a shallowing-upward trend from 15 m to 10 m in paleodepth. The interval from −12.50 to −12.35 m in depth shows an increase in form M of *B. bisanensis* of Abe (1988). Iwasaki (1992) reported that form M prefers shallower areas than form A of Abe (1988) in Ariake-kai Bay, Southwest Japan. The temporal increase in form M may indicate a slight shallowing at this horizon. Assemblage (6) at −10.00 to −8.50 m in depth represents a closed middle to inner bay at water depths of less than 10 m, and is characterized by an increase in the percentage of form M of *B. bisanensis*. This unit also shows a shallowing-upward trend. Temporal variations in paleodepth based on ostracode assemblages agree with the depositional environments reconstructed from facies

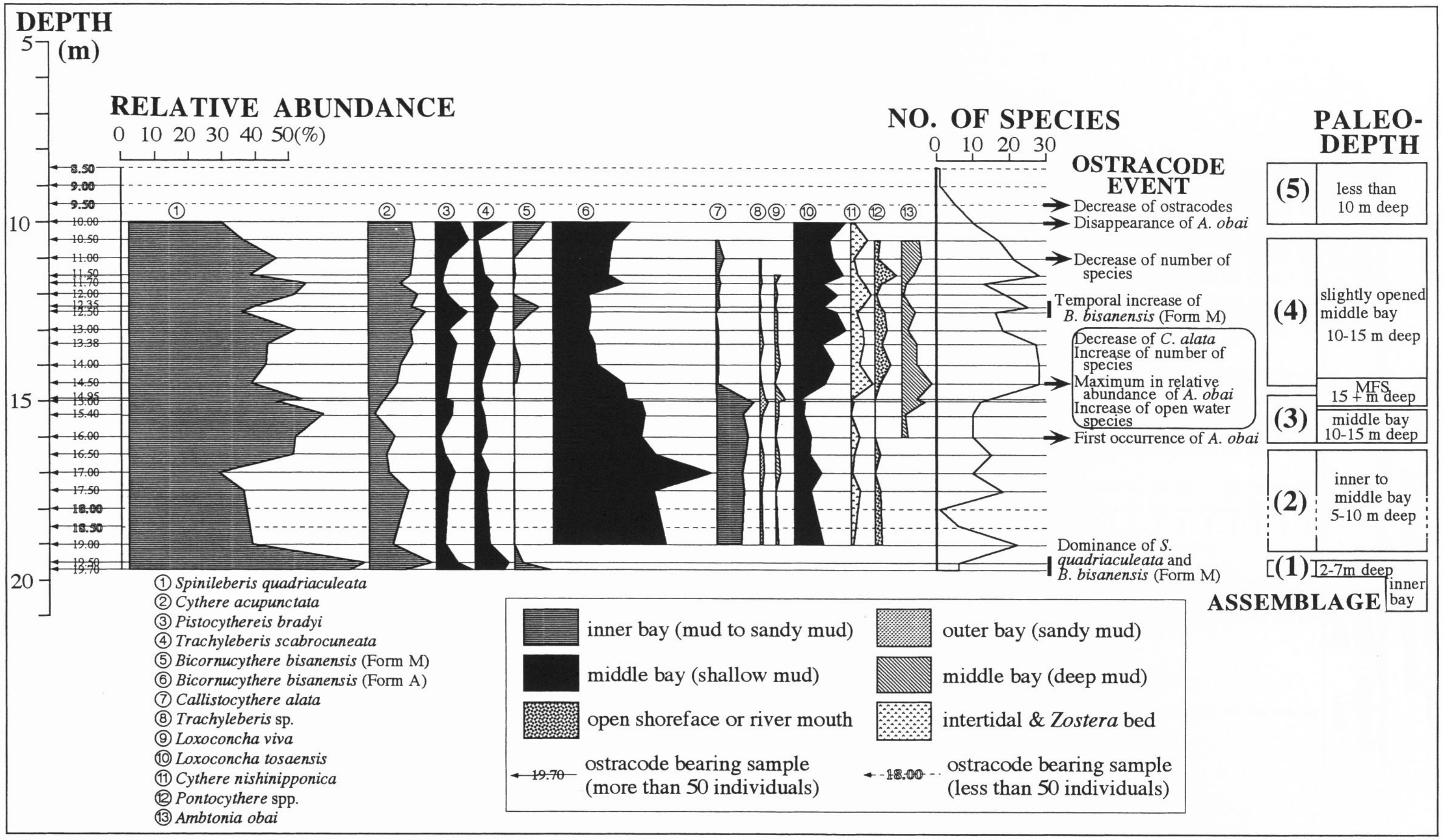


**Fig. 3.** Diagram showing columnar section for the core at Kitatsumori, sample horizons, percentages of dominant ostracodes, number of species, and a summary of ostracode events and paleoenvironments.

**Table 1.** Ages and depths of marine shell samples in a core at Kitatsumori, Osaka, Japan.

| Sample no. | Elevation (m, msl) | $\delta^{13}C$ (‰) | $^{14}C$ age (yr BP) | Calender years (cal yr B. P.) (1 $\sigma$) |
|---|---|---|---|---|
| 1 | 8.36 | −0.5 | 1740±50 | 1200 (1187−1209) |
| 2 | 9.13 | −1.2 | 1750±50 | 1200 (1188−1208) |
| 3 | 9.37 | −0.4 | 1630±50 | 1220 (1212−1229) |
| 4 | 9.92 | −1.9 | 2010±50 | 1450 (1417−1479) |
| 5 | 10.18 | −3 | 1990±50 | 1460 (1467−1520) |
| 6 | 10.71 | −1.8 | 2120±50 | 1590 (1553−1631) |
| 7 | 11.17 | 2.9 | 4260±50 | 4290 (4225−4352) |
| 8 | 11.54 | 0.4 | 3760±50 | 3600 (3547−3636) |
| 9 | 12.1 | 1.3 | 2340±50 | 1860 (1830−1898) |
| 10 | 12.3 | −0.8 | 3200±50 | 2900 (2846−2951) |
| 11 | 13.29 | −1.3 | 2870±50 | 2480 (2442−2516) |
| 12 | 13.6 | 1.6 | 2840±40 | 2670 (2648−2703) |
| 13 | 14.67 | 1.2 | 4180±50 | 4160 (4231−4085) |
| 14 | 15.07 | 0.1 | 5060±50 | 5410 (5362−5455) |
| 15 | 15.61 | 0.1 | 5740±50 | 6120 (6085−6155) |
| 16 | 16.5 | −1 | 5720±50 | 6140 (6121−6157) |
| 17 | 16.92 | 0.3 | 6530±50 | 6960 (6901−7026) |
| 18 | 17.49 | −1.5 | 7220±50 | 7610 (7567−7644) |
| 19 | 17.78 | −0.6 | 5970±50 | 6380 (6364−6404) |
| 20 | 18.37 | −2 | 7570±60 | 7950 (7902−7997) |
| 21 | 18.95 | 0.8 | 7790±50 | 8150 (8108−8192) |
| 22 | 19.91 | −0.7 | 8140±60 | 8460 (8414−8513) |
| 23 | 20.27 | −0.4 | 8270±60 | 8630 (8514−8717) |
| 24 | 20.52 | −2.3 | 8500±60 | 9000 (8772−9047) |

analysis, described above.

## A DEPOSITIONAL CURVE CONSTRUCTED FROM $^{14}C$ AGES AND ELEVATIONS

Twenty-four AMS $^{14}C$ ages were determined for molluscan shells sampled in the Holocene core from Kitatsumori, Osaka. The ages are shown in Table 1. A smoothed curve of age versus elevation can be drawn when so many densely-spaced $^{14}C$ ages are known for a given core (Fig. 2). This curve has been called a "depositional curve" by Masuda (1998). The slope of the curve represents the depositional (i.e., accumulation) rate as well as a space and time trajectory of the "sea floor" for the period of deposition (Endo et al., 1995; Masuda, 1998). The points that deviate from the depositional curve represent event deposits, such as tsunami deposits containing older shells (Masuda, 1998; Fujiwara et al., 1999a). We assume here that sediment compaction has no effect on the observed elevations.

The depositional curve in Fig. 2 shows that rates of deposition in the core were relatively high (2 to 3.5 mm/yr) in the lower part, low (1.5 mm/yr) in the middle part, and gradually increased (4.5 to 5 mm/yr) in the upper part. The slow deposition in the middle part of the core was caused by a persistent highstand in sea-level. Rapid deposition in the upper part was due to progradation of a delta system at a time of emergence during a regressive periodh. The change in depositional rate was controlled by the slope of the prograding depositional systems (Masuda and Saito, 1995). Sea-level at a particular time is obtained by plotting the value for paleodepth above a point representing the same time on the depositional curve. Paleodepths for all samples were estimated from the ostracode assemblage, as noted above. A relative sea-level curve, therefore, can be drawn by tracing the sea-level for each point as given in Fig. 2. Ages used in this paper are calendar years before present (1950), calibrated using the method of Stuiver and Braziunas (1993).

The sea-level curve constructed in Fig. 2 shows the following characteristics: the first flooding in this area was at −21.5 m in depth at about 9200 calendar years B.P.; a rise in sea-level during the transgressive stage, the so-called "Jomon transgression", occurred at a rate of about 10 mm/yr from 9000 to 8000 calendar years B.P., and 6 to 7 mm/yr from 8000 to 6000 calendar years B.P. The maximum highstand in sea-level, about +1.5 m in elevation, took place at 5500 to 5000 calendar years B.P. and corresponded to a maximum flooding that is about 800 years younger than was previously inferred (Maeda, 1980). An "intertidal age" of 5465 calendar years B.P. at +2.37 m from the western Kobe recently reported by Sato et al. (2001) is included in the obtained period of the maximum highstand in sea-level. The ephemeral decrease in relative sea-level of about −1.2 m took place at about 2200 calendar years B.P. and a relative sea-level increase of about +0.7 m was about 1700 calendar years B.P. Previously reported $^{14}C$ ages of intertidal fossil shells from other parts of Osaka by Maeda (1976) and Ota et al. (1988) show close agreement with the relative sea-level curve obtained from this core. This is the first relative sea-level curve constructed from a single continuous core.

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